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DESIGN DESCRIPTION OF THE EXTERNAL EXPERIMENTAL AREAS AT THE NATIONAL ACCELERATOR LABORATORY

April 1974

Note: This report is being issued as a TM preliminary to revision and issuance as an NAL booklet. Please direct comments, corrections, and suggestions that would make it more useful to T. E. Toohig in the Research Division.

PREFACE

Construction of the National Accelerator Laboratory was authorized in July of 1967. By summer 1970 the design parameters were sufficiently well known and construction of the accelerator itself was sufficiently advanced to allow a major effort to be launched in the experimental areas to utilize the particle beams from the accelerator. Under the firm hand of the Director, Robert R. Wilson, the experimental areas took shape during the summer and fall of 1970. In May 1972, protons from the accelerator were delivered for the first time to an external target, the hadron beam target in the Neutrino Area. Special credit for this rapid progress should go to E. L. Goldwasser, Deputy Director, and J. R. Sanford, at the time head of the Experimental Facilities Section. Credit also is due to A. W. Maschke who was responsible for the proton beam lines from the Accelerator to the experimental areas; to A. L. Read, E. J. Bleser, J. R. Orr, and R. Lundy who were primarily responsible for the design and construction of the Meson Area; to T. E. Toohig, J. Lach, and F. A. Nezrick for the Neutrino Area; to W. B. Fowler and F. R. Huson for the bubble chamber projects; and to A. W. Maschke, A. L. Read, and J. Peoples for the Proton Area. M. Awschalom of the Radiation Physics Section gave extensive help with shielding calculations.

T. E. Toohig
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I. INTRODUCTION

The NAL Accelerator in reality is four cascaded accelerators--a 750-MeV Cockroft-Walton accelerator; a 200-MeV linear accelerator; an 8-GeV rapid-cycling, combined-function proton synchrotron; and a 500-GeV separated-function proton synchrotron. It is designed to accelerate protons up to 500 GeV for use in basic research. The protons may be used directly for experimentation or may be used to produce beams of secondary particles such as pions and K-mesons, antiprotons, and neutrons for experimentation. A detailed description of the Accelerator is contained in the Design Report of July 1968.

The high energy physics research program utilizing the extracted proton beam at NAL is carried out in three external experimental areas, the Meson, Neutrino, and Proton Areas. A fourth experimental area, the Internal Target Area, located at the C-O straight section of the Main Accelerator, utilizes the circulating proton beam in the Main Ring. It will not be discussed here.

The Meson and Neutrino Areas are located north of the extraction point, immediately to the west and east, respectively, of Road A which lies along the north-south axis of the Laboratory (Fig. 1 a and b). The Proton Area lies to the east of the Neutrino Area along Road C. The accelerator system is laid out on a grid whose origin, x = 100,000 ft, y = 100,000 ft, is defined by the radius and tangent to the main-ring orbit at the extraction point at the center of the A-O straight section (see Fig. 2).

The Beam Switchyard lies between the Main Accelerator and the experimental areas. It is comprised of the main-ring extraction system and the devices for splitting and transporting the primary proton beam as far as the Meson Target Hall (Meshall), the Neutrino Target Hall (Neuhall), and Enclosure H of the Proton Area (see Fig. 3). Design, construction, and installation of the Switchyard were initially the responsibility of the Beam Transfer Group. The External Beam Systems Group in the Accelerator Division is now responsible for this work.

The variety, quality, and lengths of beam spills from the Main Ring are controlled by devices installed at appropriate places around the Main Ring. A typical proton beam spill from the Main Ring is shown in Fig. 4. The External Beam Systems Group, operating from the Switchyard Console in the Main Control Room, is responsible for steering, focusing and splitting the proton beam up to the interface with each experimental area.

The beam is split off vertically beginning at the downstream (north) end of the Transfer Hall (Fig. 5). It is bent off 97-mrad to the east (Proton Area) by a string of Lambertson-type septum magnets located at the upstream end of Enclosure B. A fraction of the undeflected beam may then be split off vertically toward the Meson Area by electrostatic wire septa halfway along Enclosure B. A system of Lambertson magnets in Enclosure C bends the split beam off to the west and under the Master Substation a total of 160 mrad to the Meson Area. The remainder of the main proton beam may be transported to the Neutrino Area. Alternatively, it may continue on to the main beam dump. The fraction of the main proton beam sent to each area, which is determined at the weekly Experimental Planning meeting, is set by varying the position of the beam on the electrostatic wire septa.

At NAL energies the configuration of each experimental area is dominated by the necessity for muon shielding. This is reflected in the relative lengths of the areas. The Meson Area, designed for 200-GeV operation, stretches some 3000 feet from a point near the Master Substation (y = 103,500 ft) to Batavia Road (Figs. 6 a and b). The Neutrino Area, designed for 500-GeV operation, stretches some 5000 feet from the Master Substation to Wilson Road. The Proton Area is also designed for 500-GeV operation, but because the targeting is done below ground level the muons are absorbed in the soil. This area stretches only to Batavia Road.

Each of the three areas has some unique characteristics. The Meson Area, the first of the experimental areas to be put under construction, was designed as a conventional area for electronic experiments in hadron beams. An array of general purpose, secondary beams would view a single target capable of accepting 5×10^{12} protons per pulse. The design would be such that approximately ten experiments could be set up at once. The facility would be more or less scaled up from similar facilities at lower energy accelerators. As noted, the area reflects the original 200-GeV design energy of the Main Accelerator. Besides the shielding, the primary beam transport to the area and the momentum capability of the secondary beams also reflect the 200-GeV design.

The Neutrino Area was designed to provide specialized beams to a variety of detector facilities. Neutrino beams were to be provided for several large electronic detector facilities and the 15-ft hydrogen bubble chamber. Muons were to be provided for a large muon electronic detector facility, and hadrons up to the maximum energy available were to be supplied to both the 15-ft and the 30-inch bubble chambers. The 400-GeV protons were to be targeted at something over 10^{13} protons per pulse. The salient features of the Neutrino Area are the 400-m, 35-inch diameter evacuated meson decay pipe (immediately downstream of the target) for neutrino production, and the 15-foot hydrogen bubble chamber at the downstream (north) end of the area. The typical muon isoflux contours around the decay pipe which give rise to the elongated shielding berm characteristic of the area are shown in Fig. 7.

The Proton Area was designed for electronic experiments using the primary beam of protons up to 500 GeV in energy and over an intensity range of 10^{10} to 10^{13} protons per pulse. In addition, beams of electrons and photons were to be installed at a later date. Approximately seven experimental stations were to be provided, viewing three separate target stations. The area is characterized by subterranean pits and heavy radiation shielding. Experimental pits are tailored to individual experiments.

II. THE MESON AREA

The Meson Area was designed to provide a conventional array of counter beams viewing a single target. The beams provide a broad spectrum of energies and intensities to accomplish a wide range of physics objectives. The beams are essentially fixed installations; experiments are brought up to the beam "spigot."

Following this concept, the beam lines are concrete enclosures tailored to the beams with earth above and around them to provide shielding against muons up to 200 GeV of primary proton energy. A detector building of relatively modest size provides weather protection, crane coverage, and utility connections for the front end of the experiments, while removable prefabricated "fingers" are tailored to each experiment downstream of the detector building. The area layout is shown in Figs. 8 and 9.

At the present time, the major experimental facility in the Meson Area is the Single Arm Spectrometer being set up in beam line M6-East. A layout of the detector end of the spectrometer is shown in Fig. 10. This facility is being built by the Elastic Scattering #96 experimental group, and will be available to the User community after completion of that experiment.

As originally conceived, the Meson Area was to accept a 200-GeV proton beam, and with it to produce six secondary beams. Four of these were to be charged-particle beams and two were to be neutral beams. One of the charged particle beams--M5, an 80 GeV/c beam--was deferred early in the planning stage, and will be revived as a minimal 40 GeV/c test beam. The other three charged particle beams, M1 (a high intensity, medium resolution beam), M2 (a diffracted proton beam), and M6 (a medium intensity, high resolution beam), had been designed to be consistent with 200 GeV/c protons incident on the target. The beams including the proton beam from the accelerator have been modified as much as possible to match the 300 GeV standard operating mode for the accelerator. Even when the secondary beams are limited in their momentum capability, their particle flux is enhanced by the 300-GeV protons.

The M2 beam was designed with a momentum capability of approximately 260 GeV/c, intended for use by Quark #75. By the addition of more magnets and power supplies, the capability of this beam has been raised to slightly over 300 GeV/c. The M1 beam line has been redesigned to operate at a maximum momentum of 280 GeV/c. To increase the usefulness of the M1 beam line, a switching magnet has been added to provide a second branch. This allows for more than one experiment to be set up at one time. The branches cannot be used simultaneously; however, beam can be switched from one to the other in approximately an hour's time. A similar magnet has been installed in the M6 beam line to create the West beam, but the momentum capability (180 GeV/c) of that line was not increased. The two neutral beams, M3 (predominantly a neutron beam) and M4 (a beam in which the larger production angle is expected to favor K^0 production relative to neutrons) were capable of functioning with 300-GeV protons on target with no changes. The properties of these Meson Area beam lines are summarized in Table I.

In addition to upgrading the beam lines to match the higher accelerator momentum, the target system (load) has been modified to enable it to handle higher beam intensities. The latest version of the target load was installed during December 1973 and January 1974 (see Fig. 11). Basically, it consists of four 20-ft long railroad cars. In operation, these are inserted into an evacuated target box embedded in heavy shielding. Protons are brought into the target load through steel collimators, which serve to define the target angle and the angular spread of the proton beam. (It is important that these two angles be controlled, to help guard against accidentally transmitting a very high intensity proton beam into the experimental area.) Following these collimators is a movable shuttle which supports eight water-cooled targets of varying lengths and diameters. Made of either beryllium or tantalum, each target is equipped with a thermocouple to monitor the effectiveness of the cooling. The shuttle permits both horizontal and vertical positioning of the targets. Downstream of the targets is a water-cooled aluminum "spoiler." Its purpose is to intercept the proton beam which has passed through the targets, and allow it to develop into a hadron shower spread out geometrically to reduce the specific energy deposit which could conceivably melt components of the target train. The spoiler is remotely controlled so that it can be positioned for optimum "spoiling," yet not appear as a secondary target during operation. Downstream of the spoiler is the first of three steel collimators which define apertures for the six secondary beam lines. This collimator contains a water-cooled aluminum core which absorbs the bulk of the power carried in by the proton beam. In addition to these collimators and targets, a number of diagnostic devices which provide information about the beam position and size are mounted on the trainload.

To produce the secondary beams, the external proton beam from the accelerator is focused onto a target in the target box. The spot size and position of the beam on the target are determined by the focusing and steering elements in the Target Hall (Meshall), under the control of the Meson Area MAC-16 computer. A SEM (secondary emission monitor) to determine the proton beam intensity, and various beam profile devices to monitor the beam on target, are provided. Monitors to determine the number of interactions in the target are also provided at the target box.

The initial beam-forming elements for all six beams are installed in the front end enclosure (Fig. 9), accessible through Service Building M2. The beam line elements are controlled through the Meson Area MAC-16 computer located in the basement of the Cross Gallery. The

MAC is backed up by an XDS Sigma 3 computer for additional flexibility. Beam line power supplies, controls, and diagnostic equipment are interfaced to the MAC-16 through a conventional CAMAC system. Timing signals, proton beam intensities, and other relevant signals from the Main Control Room are also provided to experimenters via the MAC-16/CAMAC facility. Each experiment is provided with a CAMAC crate and a TEC console and graphic display unit for communicating with the control system.

Two primary feeders rated at 7500 kVA supply 15,000 kVA of electrical power to the area. In addition, some fraction of a third feeder can be shared with Proton Area. The power loads for one typical operating configuration are given in Table I. A cooling water capacity of 13 MW is available to absorb this power. In planning the experimental program, these limitations must be taken into account.

Responsibility for operation and safety in the Meson Area is vested in the Head of the Meson Department. Operations technicians are on duty in the area around-the-clock when experiments are in progress.

A liaison physicist--a NAL staff member--is responsible for each beam line and for the experiments installed in it. This liaison physicist is the interface between other Meson Department personnel and experimenters in carrying out the best physics program for that beam. Currently assigned liaison physicists are listed in Table I.

A. L. Read, J. R. Orr and E. J. Bleser were principally responsible for initial design and construction of the Meson Area. R. Lundy and P. Koehler have been involved in subsequent modifications, and bringing the area into operation.

III. THE NEUTRINO AREA

The Neutrino Area was designed to take advantage of the unique capability of the NAL Accelerator for producing high energy, high intensity beams of neutrinos and antineutrinos. A primary tool for research with these particles is the 15-foot diameter hydrogen bubble chamber located at the north end of the area. Counter facilities are also provided for research with both narrow-band and wide-band neutrino beams. The projected energy and intensity of the proton beam from the accelerator were 500 GeV and 5×10^{13} protons per pulse, respectively, with a 4-sec repetition rate. These considerations determine the basic configuration of the area.

The neutrino flux is a slowly-varying function of the decay length available to the parent π- and K-mesons. The bubble chamber must be shielded from the flux of muons accompanying the neutrinos. The major neutrino detectors should be as close to the target as is practicable in order to maximize the solid angle acceptance of the detector. The basic parameters of the area, a 400-m decay length and 1000 m of earth shielding, represent a compromise among these three factors--decay length, shielding, and maximum solid angle.

Muons accompany the neutrinos in decay so it becomes attractive to make use of these to produce a muon beam to study electromagnetic interactions. This consideration gave rise to the muon beam and muon experimental facilities in the Neutrino Area, with ultimate muon beam momentum capability of 300 GeV/c, consistent with 500-GeV accelerator operation.

The 15-foot bubble chamber was seen to be a useful tool for hadron physics in addition to its primary use for neutrino physics. This required a hadron beam with adequate acceptance and resolution for bubble chamber use up to the maximum beam momentum of 500 GeV. With the hadron beam available it became attractive to move the small (30-inch) hydrogen bubble chamber from Argonne National Laboratory to make use of the beam to get an early look at this new energy range of physics before completion of the major facilities. The result of these considerations is shown in Figs. 12, 13, and 14.

Experimental facilities in the Neutrino Area include the 15-foot hydrogen bubble chamber in Laboratory B with a complement of hydrogen and neon as alternate target liquids; the 30-inch hydrogen bubble chamber with an associated particle tagging system; the former University of Chicago cyclotron magnet with its associated muon spectrometer in the Muon Laboratory; the 100-ton, fine-grained, liquid scintillator calorimeter and associated muon magnet at Laboratory C.

The neutrino beams available are determined by the target load used. One such load is shown in Fig. 15, preparatory to insertion into the target tube. Three such neutrino loads are available. Beam NO-1 is a momentum-selected system, which provides a dichromatic neutrino beam arising from parent particles of momenta < 200 GeV. Operation of this load is compatible with operation of the muon beam, N-1. The neutrino spectrum from the dichromatic load is shown in Fig. 16. R. Stefanski, L. Teng, and T. Yamanouchi were responsible for designing this load. Neutrino beam NO-2 is a high-current, pulsed focusing system using one horn, which provides a very broad neutrino spectrum with a 100-μsec spill. The broad band neutrino spectrum for this system is shown in Fig. 17. The short spill-length of the horn system makes it incompatible with muon beam operation. Neutrino beam NO-3 is a broad-band system using quadrupole focusing elements. Since the focusing is non-pulsate, the system can be compatible with muon beam operation. The calculated neutrino spectrum from this system is given in Fig. 18. R. Stefanski and P. Limon were responsible for design and construction.

Muon beam N-1 was installed to pick up a portion of the muons accompanying the neutrinos in the decay of π- and K- meson parents. The muon beam is basically a beam using steering magnets. Two pairs of quadrupole magnets, one in Enclosure 100 and another in Enclosure 101, focus the beam onto a 40-ft long hadron attenuator (filter) located in Enclosure 102. The quadrupole magnets in Enclosure 100 also serve to partially cancel dispersion caused by the first pair of bending magnets. An additional pair of quadrupole magnets in Enclosure 103 cancels the multiple scattering from the filter. The momentum spread of the beam (±2%) is decreased to ±0.5% by a tagging system in Enclosure 104. The Muon Laboratory, which is the experimental station fed by the muon beam, is located halfway along the Neutrino Area shielding beam (foreground, Fig. 12). After passing through the Muon Laboratory, the residual muon beam plows into the downstream earth shielding berm. The original maximum momentum of the beam was 300 GeV/c. Later substitution of 4-in. gap dipoles in the line lowered this maximum momentum to 150 GeV/c.

The N-5 hadron beam line is a high resolution, low intensity, unseparated beam which supplies particles to the 15-foot bubble chamber up to the maximum accelerator energy, 500 GeV. The N-3 beam line to the 30-inch bubble chamber is a branch of the N-5 line.

The parameters of the Neutrino Area beams are summarized in Table II. The control system in the Neutrino Area is similar to that in the Meson Area. The Neutrino Area Operations console is on the mezzanine at Lab A. The master control console is at this point.

Conventional facilities include a capacity of 22,500 kVA of ac power, comprised of three 13.8-kVA feeders with a 7500 kVA capacity. Power demand under a given set of operating conditions is given in Table III. The beam lines to the 15-foot and 30-inch bubble chambers are not designed to accept beam simultaneously. The distribution of available power is designed with this in mind. A low conductivity water (LCW) cooling system (10.5 MW) is provided for the beam lines with additional for the bubble chamber. The installed transformer capacity is 14.5 MVA for the beam lines and 13.3 MVA for the bubble chamber.

The responsibility for Neutrino Area operations rests with the Head of the Neutrino Department. The Neutrino Area Crew Chief is responsible for detailed operations around-the-clock with respect to non-bubble chamber operations. An Operating Engineer for the 15-foot bubble chamber and Crew Chief for the 30-inch bubble chamber have responsibility for their respective chambers.

T. Toohig and J. Lach were primarily responsible for initial design and construction of the Neutrino Area other than the bubble chambers. W. Fowler was responsible for both the design and construction of the 15-foot bubble chamber and the move of the 30-inch chamber from Argonne National Laboratory. T. Yamanouchi designed the N-1 beam line, and J. Lach and S. Pruss designed the N-3 and N-5 hadron beam lines. J. R. Orr is the recent Department Head, and F. R. Huson is now in charge.

IV. THE PROTON AREA

The Proton Area is the third of the experimental areas serviced by the extracted proton beam. It evolved out of a request for facilities for experiments utilizing protons directly with the full intensity and energy of the primary proton beam. The demand for beams of secondary and tertiary particles for the first round of experiments was already satisfied by the Meson and Neutrino Area beams. The severe radiation problems involved in targeting the full proton beam, together with the desire for providing several such experimental stations in the area made it attractive to take advantage of the radiation protection afforded by placing the target stations below ground level. For Proton Area experiments the beam is intimately coupled to the experimental apparatus, so the target halls (pits) are tailored to the experiments to be run in them.

The area consists of three such pits, Proton-East, Proton-Central, and Proton-West. A two-way splitting station beginning in Enclosure H of the Switchyard splits the beam between two of the three target stations, or sends the entire beam to one station, according to the experimental schedule. The design of the target stations is such that work can go on in one pit while the others are operating. An aerial view of the experimental pits is shown in Fig. 19, they are shown schematically in Fig. 20.

The very high radiation levels to be expected from targeting the full intensity and energy of the accelerator (5×10^{13} protons/4-sec at 500 GeV) are handled in Proton Area by densely packing shielding material, chiefly steel, around the target. This has the twofold effect of "packaging" the residual radiation in a relatively small volume of inert material and preventing the walls of the target enclosure from becoming radioactive. The active beam monitoring and shaping elements tailored to each experiment are inserted into the core of the close-coupled shield in what is called a "target drawer." A target drawer being inserted into the close-coupled shield is shown in Fig. 21.

The target drawers are rigged to the pit level in shielded coffins through an access pit in Service Building P-2. They are moved to the appropriate target hall through the labyrinth shown in Fig. 20. The coffin is then manually rigged into line with the shield and the drawer is rolled out of the coffin into position. The upstream beam elements are then put into position for operating after the coffin and handling equipment have been moved.

At present there are no secondary beams in the conventional sense in the Proton Area. The layout for the first group of experiments is shown in Fig. 22.

Up to the mini-split, the proton beam is under the control of the Switchyard system operated from the Main Control Room. Control of the proton beam through the split and onto the experimental targets, as well as the beam elements for each experiment, is handled by the Proton Area MAC-16 backed up by the Experimental Area

Sigma-3. Elements upstream of the target are controlled by Proton Department personnel. Control of downstream elements is assigned to the appropriate experimenter consoles.

Power, 15,000 kVA ac, is supplied by two 7500 kVA feeders. Part of this may be shared with the Meson Area. A typical load distribution is shown in Table IV. Low conductivity water (7.5 MW capacity) is provided to handle this load, and 13.5 MVA of 480 V transformer capacity is installed.

A Technician is on duty at all times in the Proton Area Control Room near the P-2 Service Building. He is responsible for keeping the proton beam on the appropriate targets and for security of the area.

Initial design and construction of the Proton Area were due to A. W. Maschke and A. L. Read. J. Peoples continued the design and construction effort and is largely responsible for bringing the area into full operation.

V. AVAILABLE BEAMS AND FACILITIES

A summary of the assembly of beams and facilities available to experimenters at NAL is shown in Fig. 23. The background material used in preparing this report is listed on pages 25 through 30. A complete set of these documents is on file in the Research Division office.

Table I. The Meson Area Beam Lines

Beam Line	Production Angle (mrad)	Maximum Momentum (GeV/c)	Solid Angle (μsr)	Momentum Acceptance ($\Delta p/p$)	Approx. Flux per 10^{13} Interacting Protons at 300 GeV	Power Usage: Momentum (GeV/c)	Power Usage: Estimated Power (kW)	Liaison Physicist
M1 High energy medium resolution beam	3.91	200	2.0	±0.1%→±2.0%	10^7 π at 150 GeV	200	2100	A. Wehma
M2 Diffracted proton beam	1.75	300	0.22	±0.1%→±1.4	10^{10} p at 200 GeV	300	900	H. Haggert
M3 Neutron beam	1.75	-	Variable	-	$10^8/\mathrm{cm}^2$	-	350	H. Haggert
M4 K^0 beam	6.5	-	Variable	-	$10^6/\mathrm{cm}^2$	-	900	H. Haggert
M5 Test beam	20.0	40	6.2	±0.05%→±0.5%	10^6 π at 50 GeV	40	300	---
M6 High energy, high resolution beam	3.05	200	1.34	±0.014%→1.0%	10^7 π at 100 GeV	-	5600	S. Ecklund

Table II. Parameters of Neutrino Area Beams.

Beam Line	Production Angle mrad	Maximum Momentum GeV/c	Solid Angle μsr	Momentum Acceptance $\Delta p/p$	Approx. Flux per 10^{13} Interacting Protons at 300 GeV
NO-1 Quadrupole, narrow-band neutrino beam	0	300[a] 200[b]	4 - 16	±5%	10^6 Neutrino through 1 m^2
NO-2 Broad band, horn focus neutrino beam	0	500	2800	5-500 GeV	10^{10} Neutrino through 15-ft bubble chamber spectrum peak at 20 GeV
N1 Muon beam	0	200		±2%	10^6 μ^+ at 150 GeV/c
N3 Hadron beam for 30-in. bubble chamber	Variable $0 \leq p_T \leq 1$ GeV/c	500	0.3	±0.07%→±1.2%	Sufficient for bubble chamber
N5 Hadron beam for 15-ft bubble chamber	Variable $0 \leq p_T \leq 1$ GeV/c	500	0.3	±0.02%→0.6%	Sufficient for bubble chamber

[a]On target.

[b]Secondary.

Table III. Power Usage in the Neutrino Area[a]

	Secondary Momentum (GeV/c)	Estimated Power (kW)
General load in service buildings N-1, N-2, N-3	-	1295
Proton focusing magnets	300	272
Target train load	150	113
N7/N9--By-pass and common hadron beam	300	170
N3--30-inch bubble chamber beam line	300	597
N5--15-foot bubble chamber beam line	300	1368
N1--muon beam	150	1356
Cyclotron magnet	-	2410
30-Inch bubble chamber and magnet	-	6355
15-Foot bubble chamber	-	1065
General load in experimental areas (lights, etc.)	-	306
Additional load for experiments	-	910
	Subtotal	16,207

[a]Assuming 300-GeV protons on target.

Table IV. Power Usage in the Proton Area[a]

	Secondary Momentum (GeV/c)	Estimated Power (kW)
Enclosure H		
Vertical bends and quads common to all beams	300	300
P-Central beam	300	135
P-East beam	300	225
P-West beam	300	450
General load in beam area service buildings	-	1000
General load in experimental area (observatory)	-	1000
P-East beams	300	800
Power for experiments (E100 and E87)	-	270
P-Central beams	300	400
Power for experiments (E70)	-	500
P-West beams	300	400
Power for experiments	-	200
	Subtotal	5,980

[a]Assume 300 GeV on target.

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31. TM-305 (2910) "The Dump-Box for the Neutrino Area" (May 1971) M. Palmer and R. Stefanski.

32. Memo, F. Krzich (8 June 1971) "Neutrino Beam Dump Cooling System."

33. TM-301 (2010) "Aluminum Beam Stop for the Neutrino-Area Dump Box" (October 1971), M. Palmer and R. Stefanski.

34. TM-467 The Downstream Beam-Stop and Target Box for the Neutrino Area.

C. Muon/Hadron Shielding

35. Memo; M. Awschalom (19 February 1971) w/attach. "Review of the Muon Shielding of the Neutrino Laboratory."

36. Notes "Area I Shielding," July 1970.

37. Notes of Area I Meeting, August 6, 1972.

38. Experimental Area I Notes, September 13, 1970.

39. Notes on Area I Meeting of September 14, 1970.

40. TM-259 (1100.4) "Muon Shielding: Studies of Homogeneous Shielding for a Neutrino Facility" D. Theriot and M. Awschalom (19 August 1970).

D. Beams

41. TM-472 "500 GeV Neutrino Beams at NAL" D. C. Carey et al.

42. D. C. Carey et al., "Wide Band Neutrino Beams with Quadrupole Focusing" Proc. National Accel. Conf. 1971.

42a. TM-478 "The NAL Neutrino Horn System" F. A. Nezrick et al., 1974.

43. P Limon et al. "A Sign-Selected Dichromatic Neutrino Beam" NAL-Pub-73/66-EXP.

44. TM-469 (2200) "Summary of Triplet Train NOT" R. Stefanski et al. (16 February 1974).

45. F. A. Nezrick, "A Monoenergetic Neutrino Beam Using Current-Sheet Focusing Elements," Proc. National Accel. Conf., 1971.

46. TM-285 (2254.000) "Hadron Beams in the Neutrino Area," J. Lach, S. Pruss (25 January 1971).

47. TM-298 (2254.000) "Instrumentation of the Hadron Beams in the Neutrino Area," J. Lach, S. Pruss (28 April 1971).

48. TM-418 (2254) "On the Care and Feeding of Bubble Chambers, etc.," T. E. Toohig (May, 1973).

49. TM-429 (2252) "Muon Beam: N-1," P. Limon, et al.

E. Controls and Security

50. Memo, R. Stefanski (2 April 1973) "Neutrino Area Controls Nomenclature."

51. Memo, R. Stefanski (10 April 1973) "Control Commands in Neutrino Area Controls Software."

52. TM-463 (2290) "Neutrino Area Radiation and Electrical Security System," R. Parry, T. Toohig, E. Woods.

F. Detectors

53. Letter, H. Anderson to J. Sanford (14 December 1970) w/attach. University of Chicago Cyclotron Magnet Description and Specifications.

54. "ANL 30-Inch Bubble Chamber Safety Report for NAL Operations," V. J. Sevcik (19 March 1971).

55. "The NAL 15-Foot Bubble Chamber and the Use of Track-Sensitive Targets in Neutrino Experiment," F. A. Nezrick, International Conf. in Instrumentation for High Energy Physics, Dubna, Sept. 8-12, 1970.

56. 15-Foot Bubble Chamber: Design of Optics for the NAL 15-Foot Chamber, F. R. Huson (12 April 1971).

57. "Safety Report, 15-Foot Bubble Chamber," (November 1970) National Accelerator Laboratory.

58. "Safety Report, 15-Foot Bubble Chamber," (July 1972), 3 Volumes, National Accelerator Laboratory.

59. "Design Report 25-Foot Bubble Chamber," (October 1969), National Accelerator Laboratory.

Fig. 1(a). Aerial view of the NAL site, taken in April 1973.

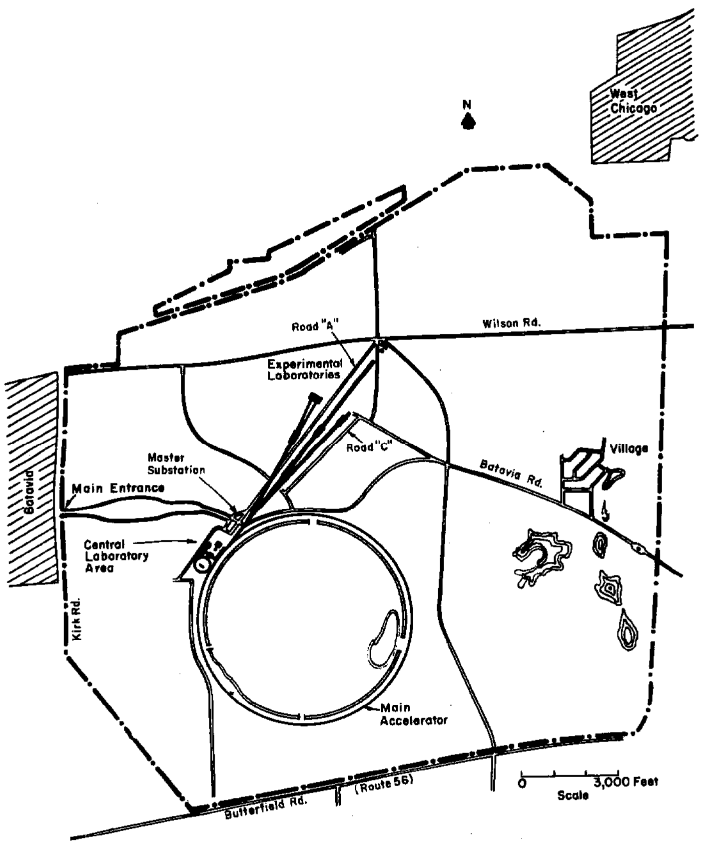

Fig. 1(b). Diagram of the NAL site.

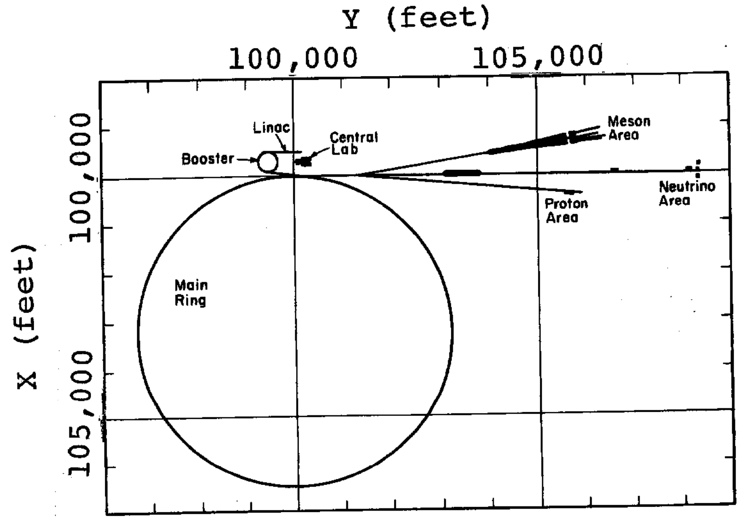

Fig. 2. Reference grid of the NAL site.

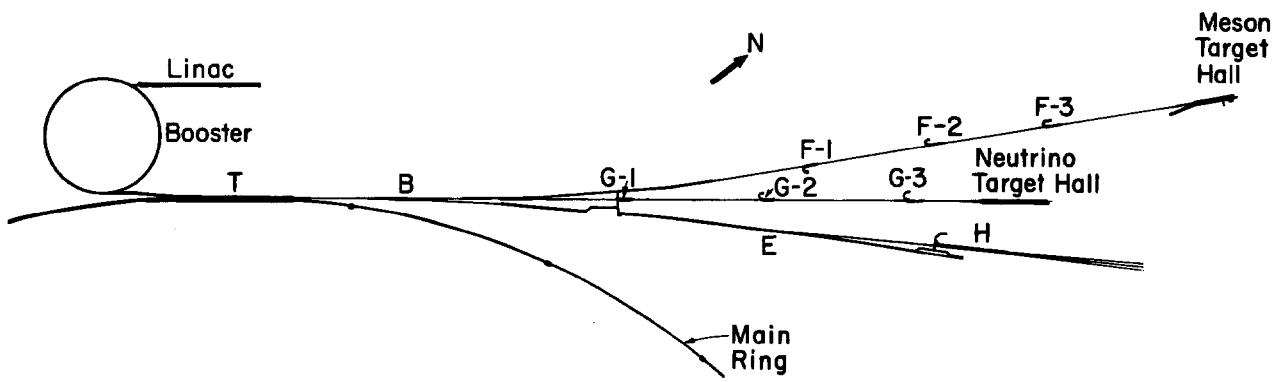

Fig. 3. Diagram showing the layout of the Switchyard. Transfer Hall is at T.

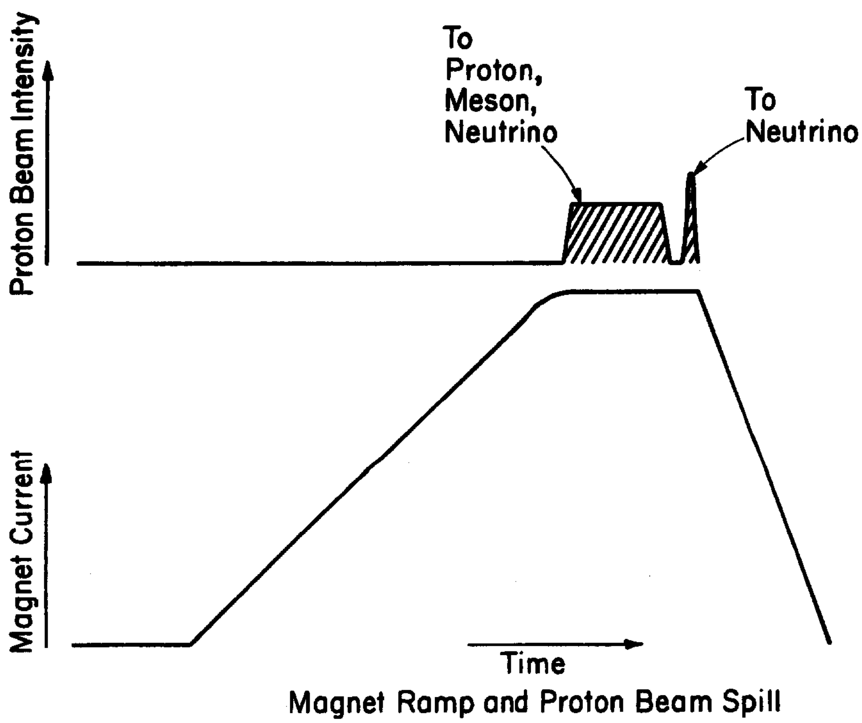

Fig. 4. Diagram showing main-ring magnet ramp and proton beam spill.

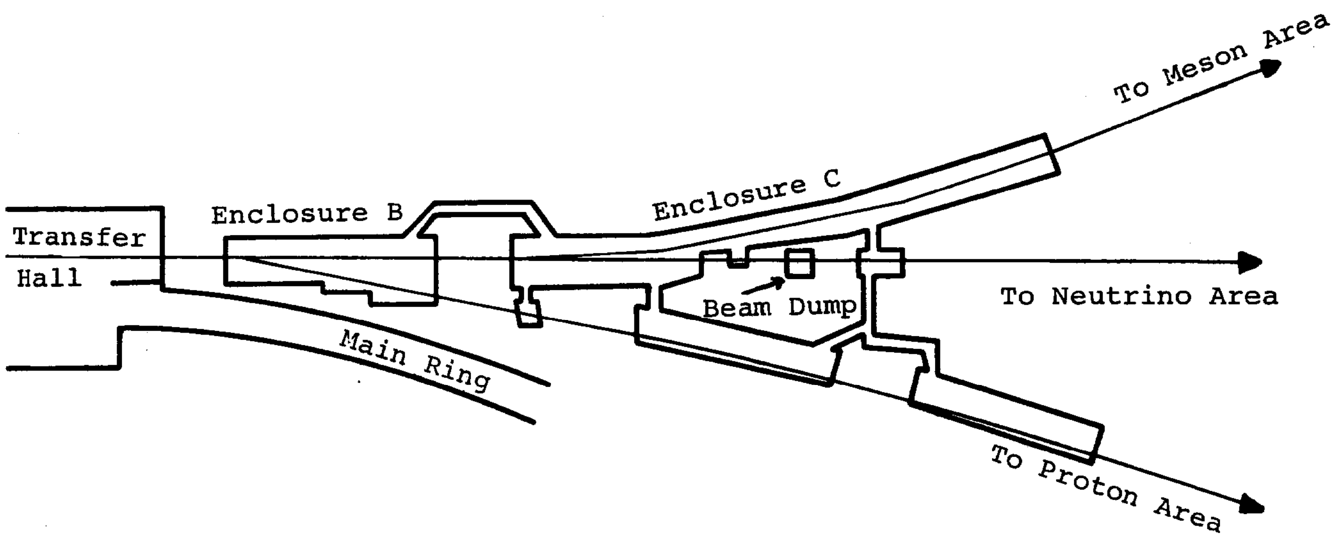

Fig. 5. Diagram showing proton beam Switchyard enclosures.

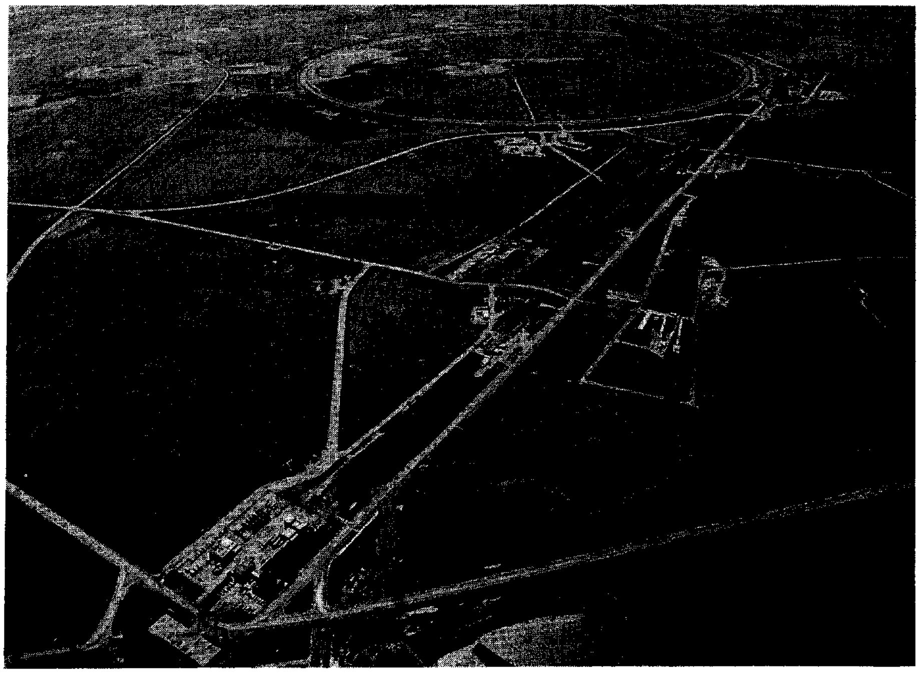

Fig. 6(a). Aerial view of the experimental areas, taken in April 1973.

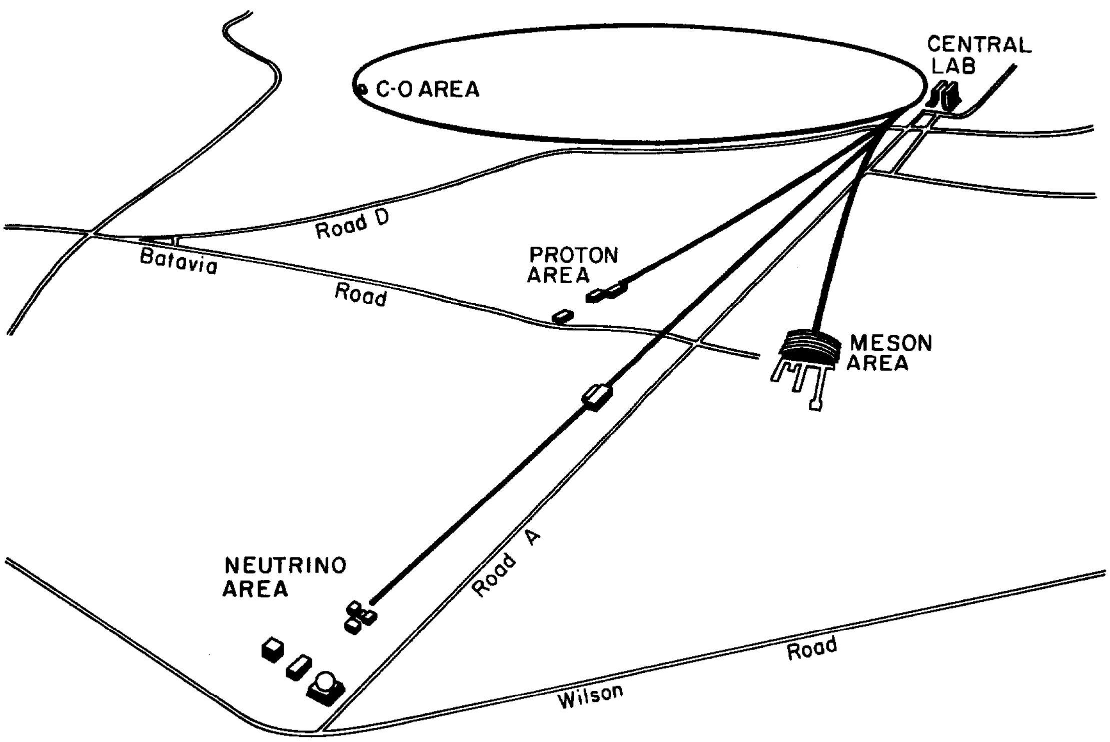

Fig. 6(b). Diagram of the experimental areas.

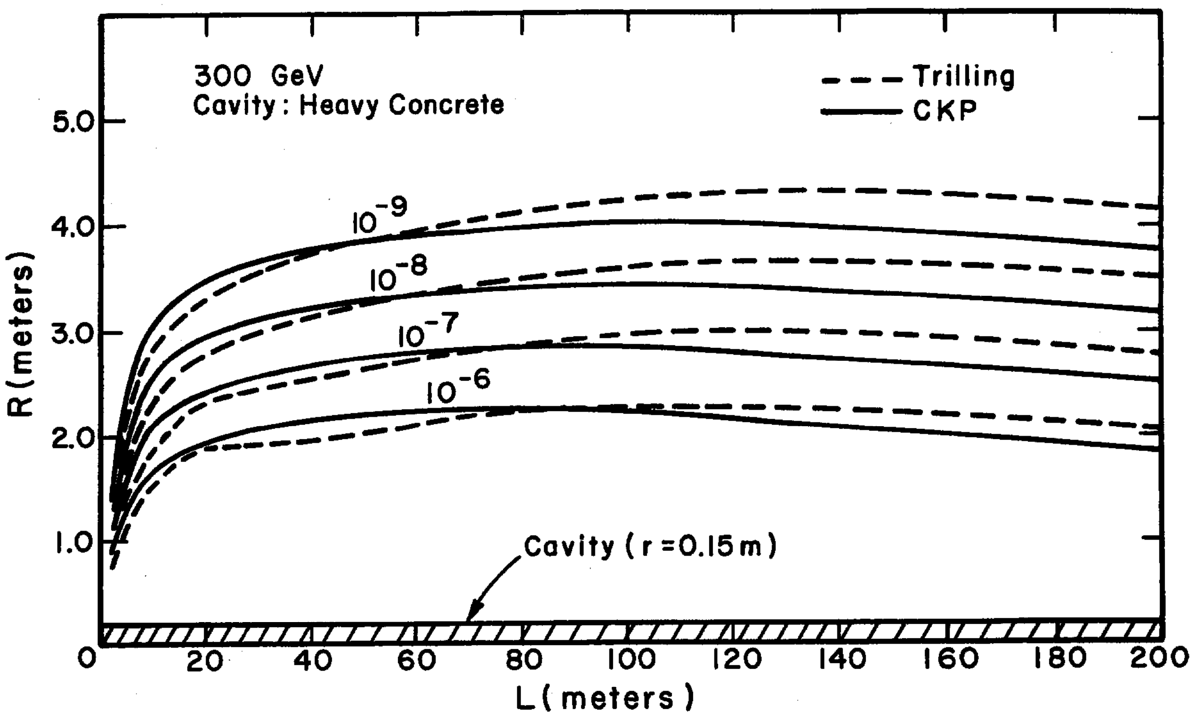

Fig. 7. Diagram showing muon isoflux contours in a homogeneous shield.

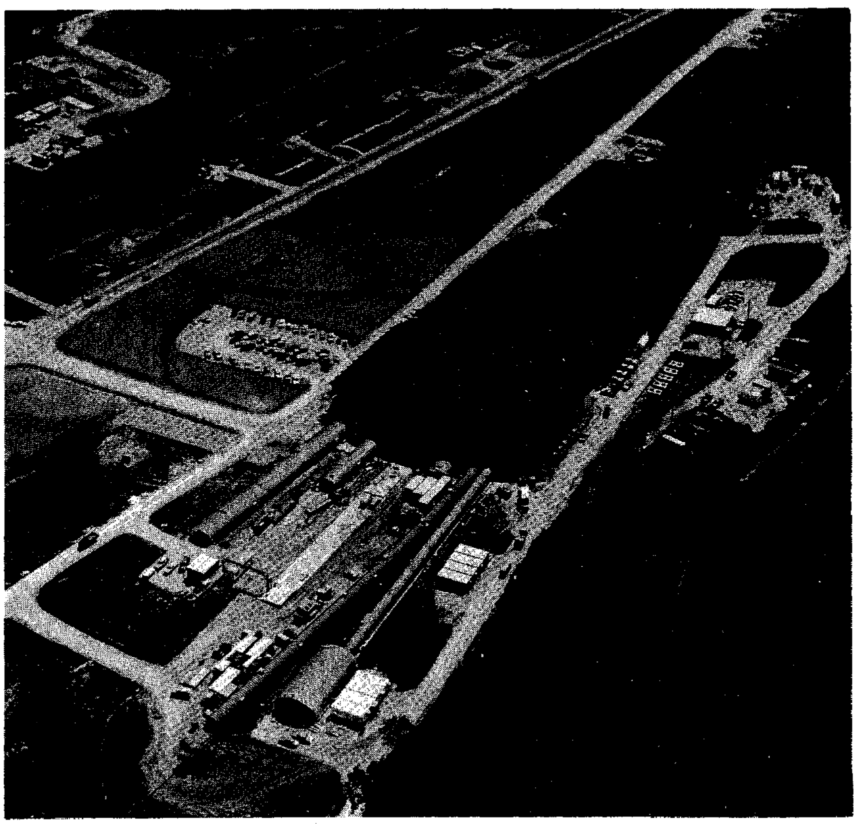

Fig. 8. Aerial view of the Meson Area, taken in September 1973.

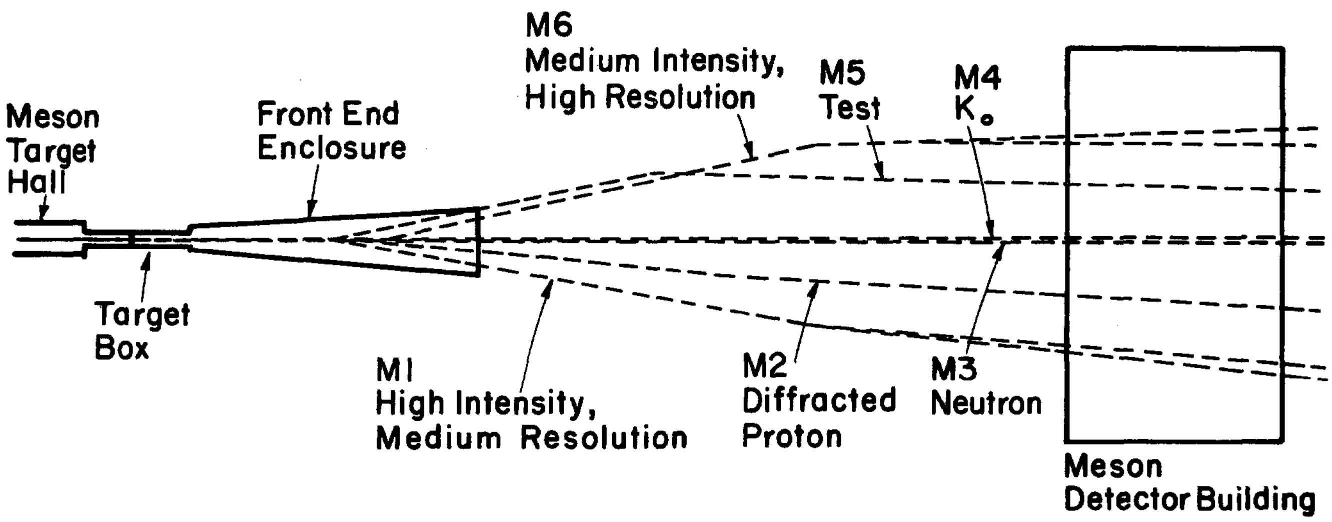

Fig. 9. Diagram showing beam lines in the Meson Area.

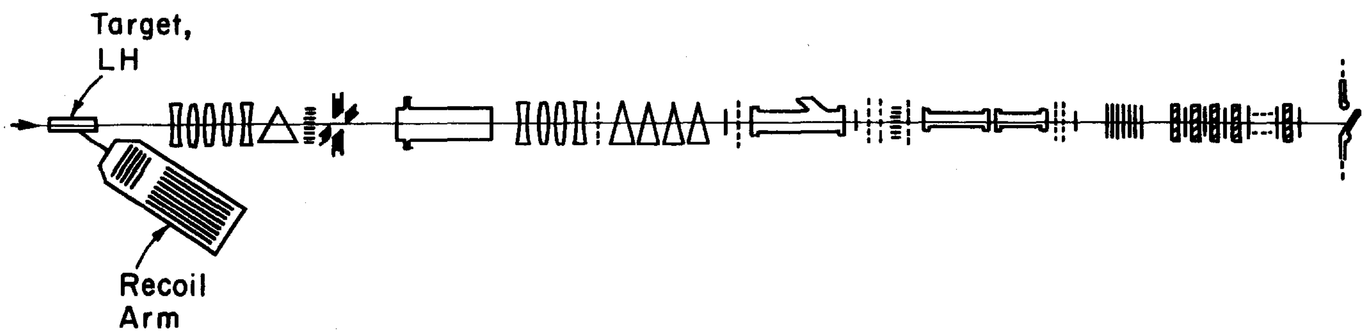

Fig. 10. Diagram of the single-arm spectrometer installed in the M6 beam line in the Meson Area.

Momentum range:	50 to 180 GeV/c
Dispersion:	3.88 cm/%
Angular Acceptance:	$\Delta\Omega$ = 0.60 sr
Momentum Acceptance:	$\Delta p/p \pm 2.14\%$

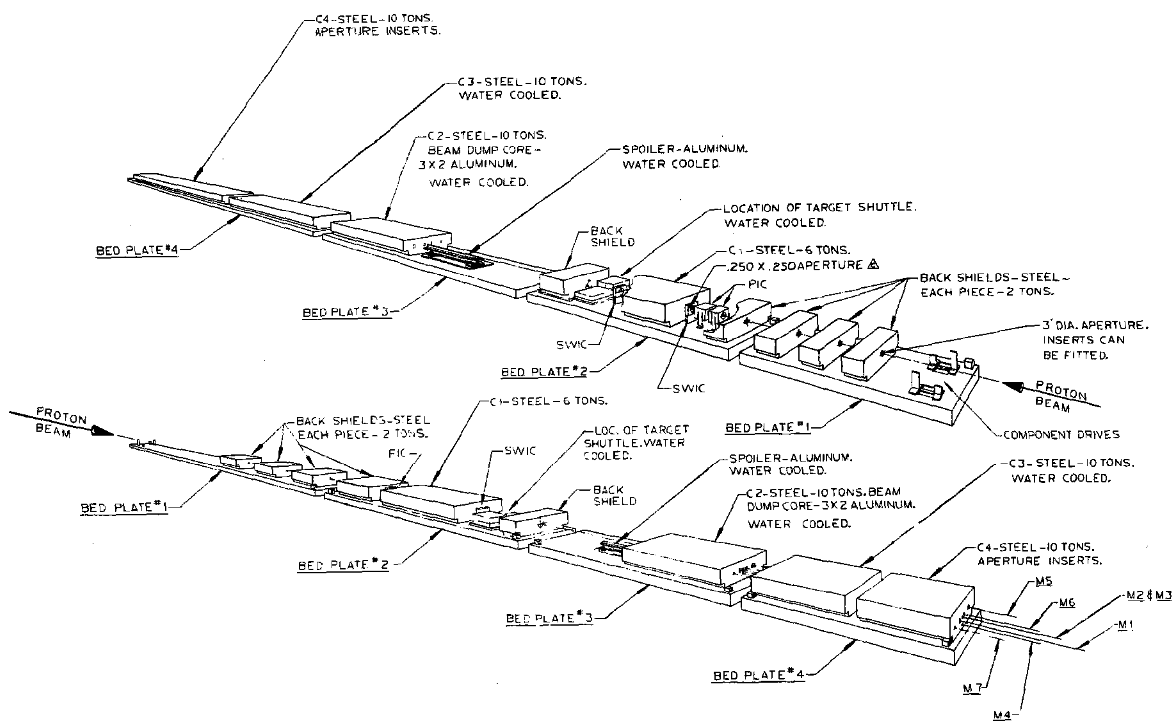

Fig. 11. Isometric view of the Meson Area target load.

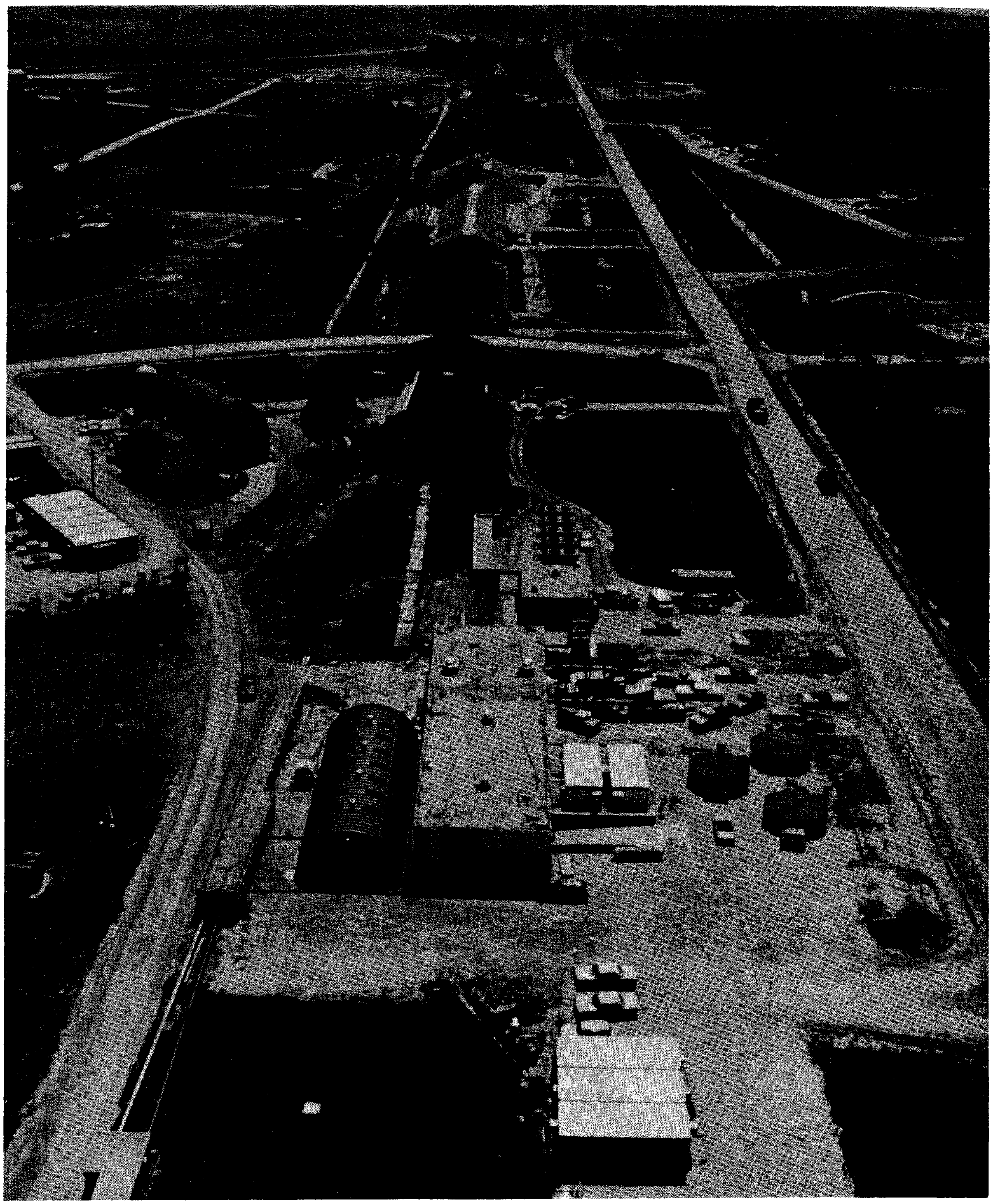

Fig. 12. Aerial view of the Neutrino Area, looking south toward the main accelerator from the Muon Laboratory. Taken in April 1974.

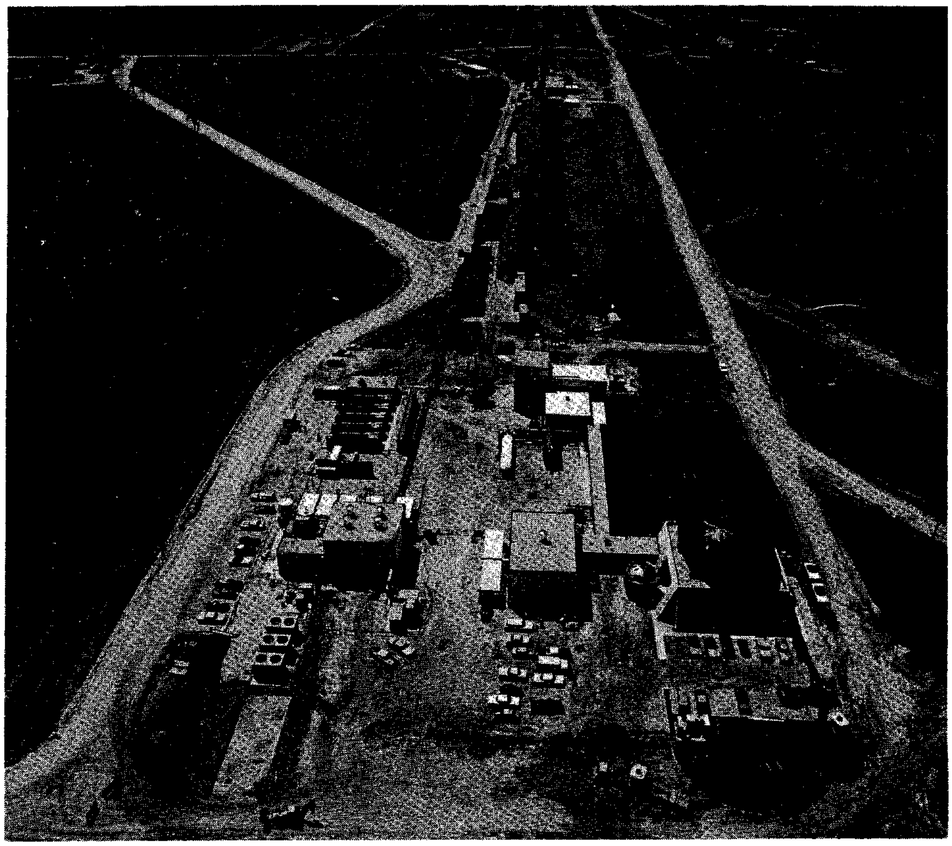

Fig. 13. Aerial view of the Neutrino Area, looking south from the bubble-chamber area. Taken in April 1972.

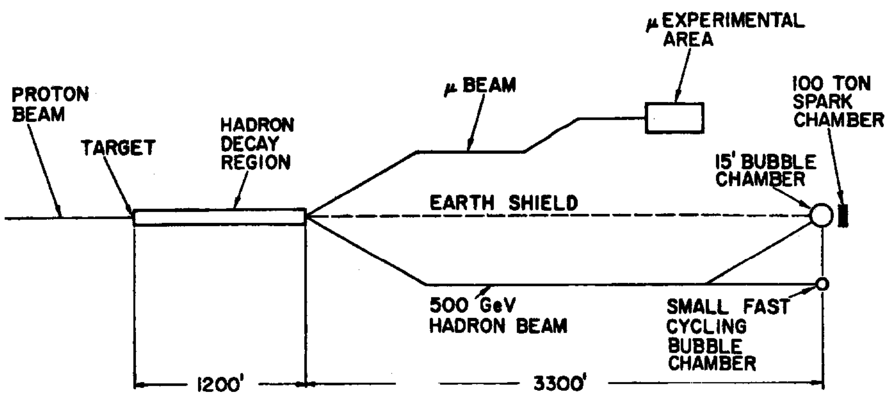

Fig. 14. Diagram of the Neutrino Area, showing the beam lines and experimental facilities.

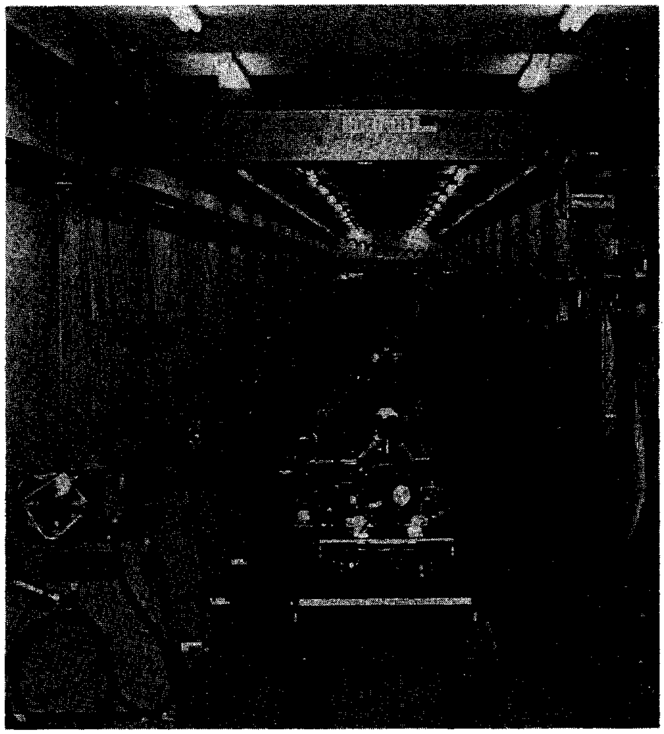

Fig. 15. View of the dichromatic neutrino beam load in Neuhall.

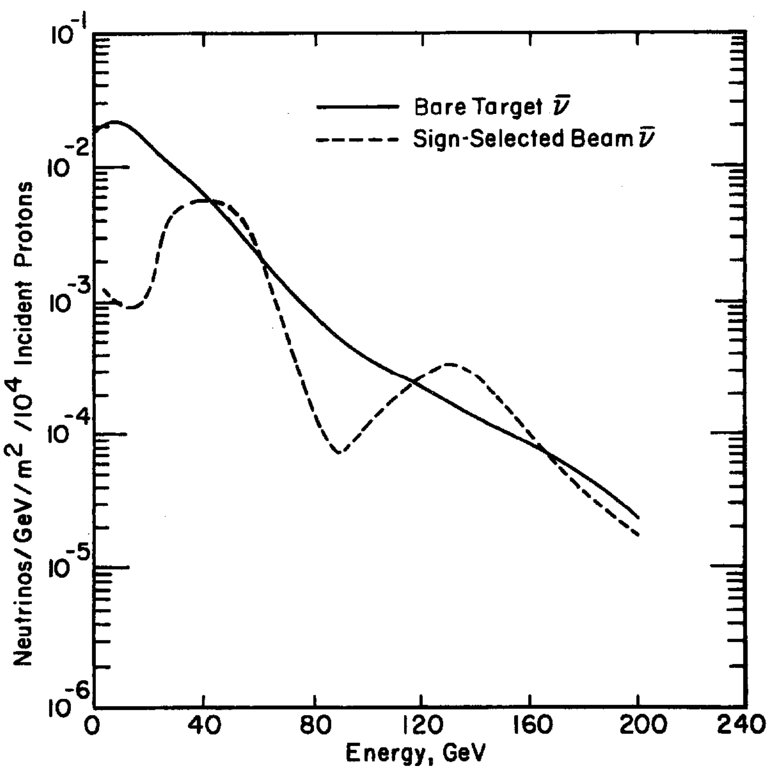

Fig. 16. Neutrino flux from the dichromatic neutrino beam, NO-1.

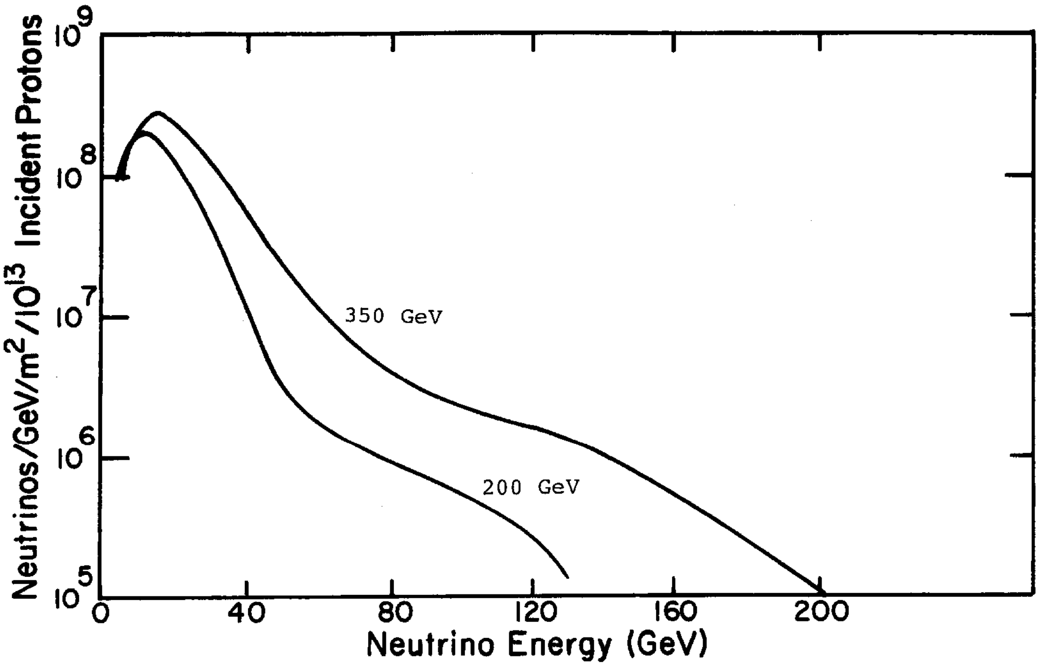

Fig. 17. Neutrino flux from the high current horn focusing system, NO-2, with 200-GeV and 350-GeV incident protons, using the Hagedorn-Ranft production model.

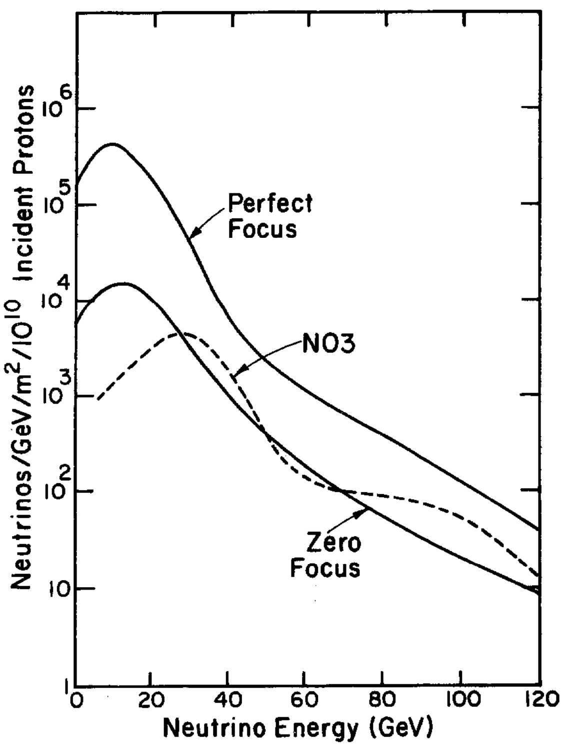

Fig. 18. Neutrino flux from the quadrupole triplet beam, NO-3, with 200-GeV incident protons, using the CKP production model.

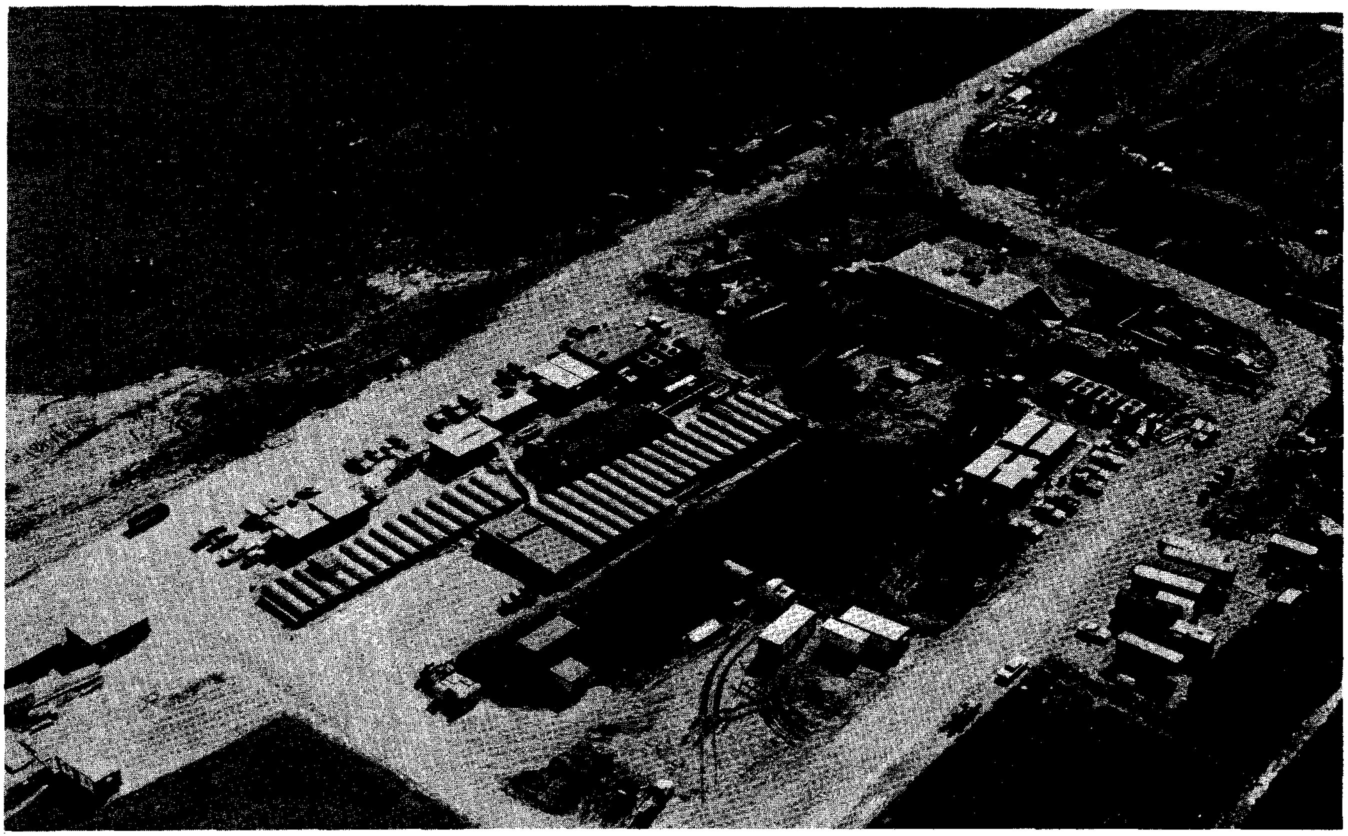

Fig. 19. Aerial view of the Proton Area, taken in October 1973.

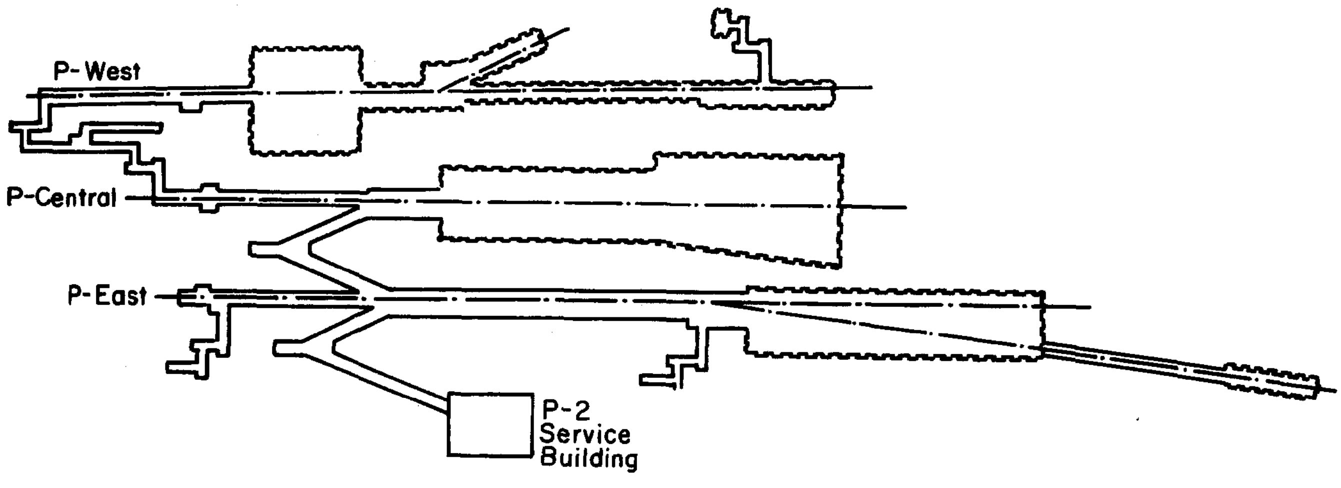

Fig. 20. Diagram of the Proton Area.

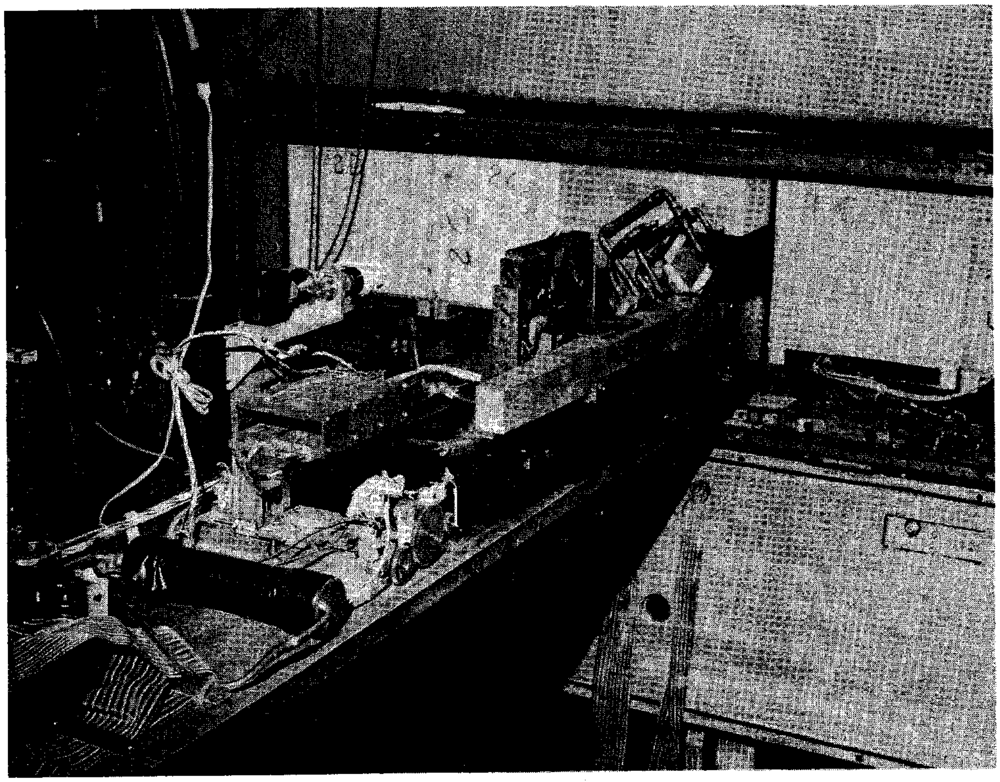

Fig. 21. A target drawer being inserted into close-coupled shielding, in the Proton Area.

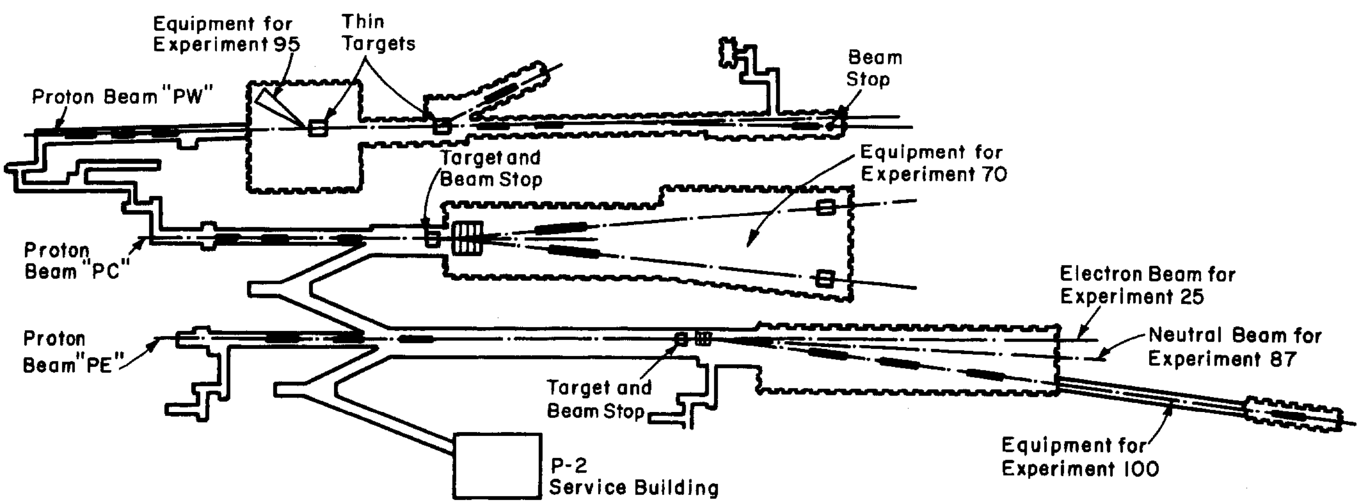

Fig. 22. Diagram showing the location of experimental equipment set up in the Proton Area in April 1974.

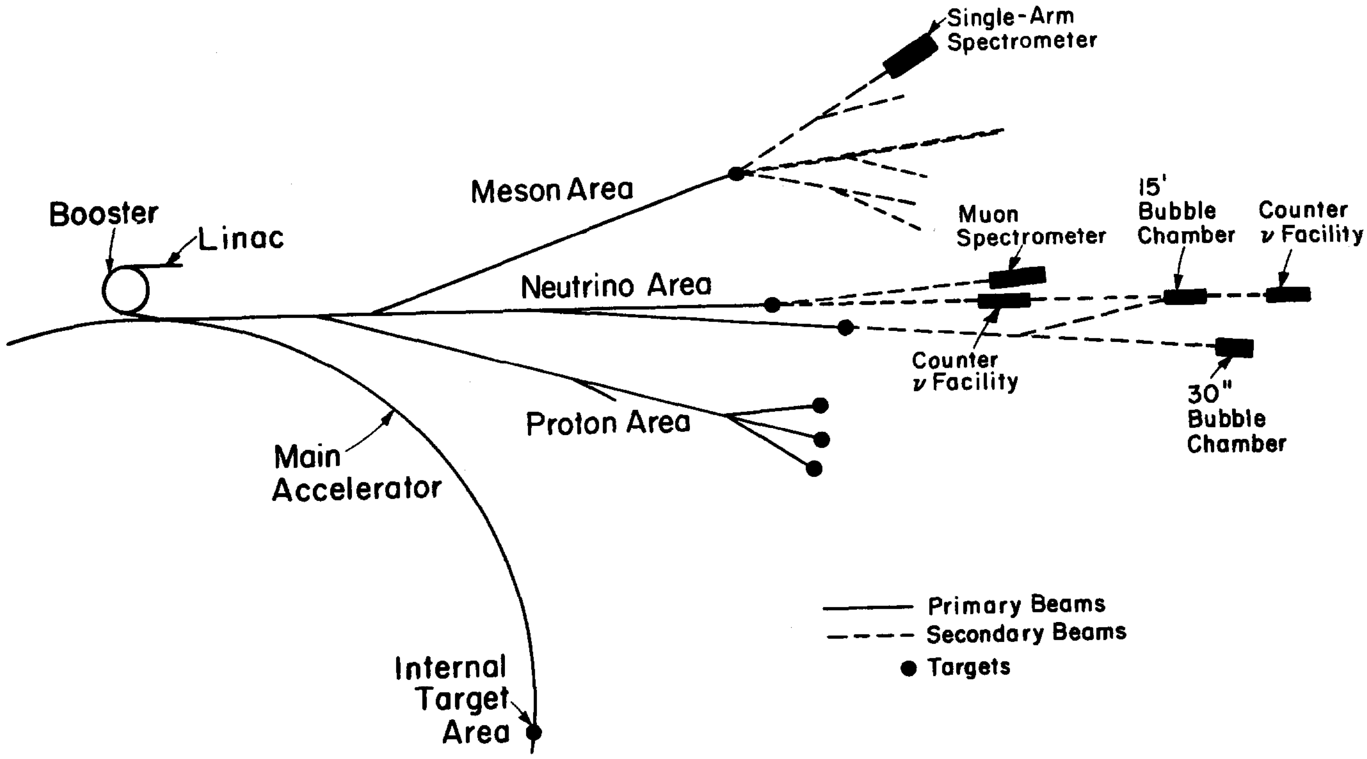

Fig. 23. Diagram showing the experimental beams available at NAL in spring 1974.